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PLASMA CATHODE THYRATRON

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Electronic Components Division
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September 1978

First Tri-Annual Report for Period 1 September 1977 to 30 December 1977

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The objective of this work is to provide a thyratron type device which is capable of cold-start operation; thus eliminating the need for standby power.

A replica of a cold-cathode triode, described by Vagin in the Russian literature, was built and tested. The results do not support Vagin's description of its operation.

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20. Abstract (continued)

A triode of our own design operates satisfactorily without filament power. A keep-alive or ignitor electrode is proposed as a solution to the high grid breakdown voltage and anode jitter found during the start-up period.

ABBREVIATIONS AND SYMBOLS

eag	Anode to grid voltage drop
Ebb	Anode supply voltage
egy	Peak forward grid voltage
Ek	Cathode supply voltage
ekg	Cathode to grid voltage drop
epy	Peak anode voltage
Eres	Reservoir voltage
etd	Tube voltage drop
ib	Peak anode current
iga	Grid current at time of peak anode current
ika	Cathode current at time of peak anode current
Ires	Reservoir current
prr	Pulse repetition rate
tac	Anode commutation time
tad	Anode delay time
Δtad	Anode delay time drift
tj	Variation in anode delay time
tkd	Cathode delay time
tp	Pulse duration
Zg	Grid circuit impedance

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1.0 INTRODUCTION

a. Foreword

This First Triannual Report describes the work accomplished during the period 1 September 1977 to 30 December 1977 under USAECOM Contract DAAB07-77-C-2704, entitled "Plasma Cathode Thyratron." This work was performed by EG&G, Inc., 35 Congress Street, Salem, Massachusetts 01970.

b. Background

The objective of this program is to provide a thyratron-type device which is capable of cold-start operation. The elimination of standby power consumption prevents the usage of a thermionic cathode. It also prevents maintaining the tube's internal atmosphere by incorporating a thermally equilibrated hydride reservoir into the tube in the usual fashion. This latter problem is readily solved by appealing to current technology, and is not treated herein.

The principal problem, then, is to minimize the effects of the arcing which results from the use of a cold cathode. If arc phenomena can be confined to the cathode cavity, it is expected that the anode discharge will retain the favorable characteristics found in the normal thyratron.

Cold-cathode operation is also expected to require that more attention be paid to reducing anode delay time and jitter than is required in the normal thyratron.

Two past developments are of special interest to this work. Vagin*, in the Russian literature, described the operation of the Autron, a cold cathode triode. A separate cathode PFN supposedly generates a plasma which, in conjunction with an open grid, forms a "plasma cathode" for the anode pulse, thereby preventing arcing.

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*Vagin, L.N. and Ivleva, L.G. "The Autron — A Controlled Plasma-Cathode Gas-Discharge Device." Pribory i Tekhnika Eksperimenta 6 157 (1968).

Although Vagin's explanation of the mechanism by which this tube confines arc phenomena to the cathode cavity is confused, his data indicate that this simple device did operate satisfactorily under conditions of practical interest for thyratron applications.

More recently, EG&G developed a hot cathode, grounded-grid thyratron. The pertinence to this discussion is that this tube is specifically designed to permit arcing of the anode pulse to the grid. The tube parameters are contrived to force the arc spot to the underside of the grid-baffle assembly, permitting the anode cavity plasma to retain the characteristics of the normal glow discharge.

The approach taken in this work is to similarly confine arc phenomena to the cathode cavity and to minimize the amount of sputtering by using a cathode and also, if necessary, a grid baffle impregnated with low work-function material. Delay and jitter associated with cold-cathode operation will be dealt with by incorporating either, or both, a keep-alive and an ignitor in the tube. The interaction between cold-cathode triggering requirements, grid design, and tube holdoff voltage will also require investigation.

c. Operational Requirements

The tube requirements specified by this Contract consist of operating in two modes, designated as Operation I and II, which are described in Table 1.

Table 1. Tube operating requirements.

Parameter (units)	Operation I	Operation II
epy (kV) min	20	20
ib (A) min	500	250
tp (μsec)	1	5
prr (Hz)	1000	500
Plasma Cathode Pulse Width (μsec) max	2	7
Plasma Cathode Peak Current (A) max	500	250
egy (V) max	500	500
Zg (ohm)	50	50
tj (μsec) max	0.010	0.010
Δtad (μsec) max	0.5	0.5
Life (hrs) min	500	500
Shots	1.8×10^9	0.9×10^9
Coulombs	900,000	2,250,000

2.0 PROGRAM STATUS

a. Summary

The first portion of this program was concerned with establishing test equipment, tube design and construction, and testing of the tube prototypes.

A simple modulator for operating at 1 pps with a 5-kV maximum anode voltage was designed and built. This test kit consists of anode and cathode cavity PFN's and power supplies, a mercury relay and timer for switching the cathode PFN, and a reservoir power supply. PFN capacitors for upgrading the test kit to the OPI conditions, given in Table 1, have been ordered.

The other major test facility is a demountable tube system which permits rapid assembly of tubes with various internal geometries for preliminary evaluation. In addition to reducing assembly time and parts costs, the glass envelope of the demountable tube permits visual observation of the discharge. The tube structures and hydrogen flow system of this facility are presently under construction.

Two experimental tubes have been built. One is a replica of Vagin's loosely baffled Autron. This replica is used to evaluate Vagin's claims for his cold-cathode tube. The second tube is also a triode, but has an impregnated cathode to reduce the arc-sputtering attendant upon cold-cathode operation. It also incorporates a less open grid and baffle design which provides a constant grid-to-baffle offset so that systematic study of the effects of varying the extent of baffling is facilitated.

The replica of Vagin's Autron, the HY-3203-007, has been characterized. Operating this tube over a wide range of cathode/anode current ratios, 0 to 1.2, does not measurably affect the anode current pulse, as claimed by Vagin. In particular, no evidence of anode cavity glow-arc transitions, if they took place, could be seen.

Voltage drops across the anode and cathode cavities seemed somewhat larger than found with known glow discharges of similar geometry (i.e., thyratrons), but these measurements were not sufficiently precise to make positive conclusions.

The open self-baffling grid specified by Vagin results in short anode commutation times, but also in very poor tube holdoff. At an internal pressure of 430 microns the anode holdoff voltage is only 9 kV, as contrasted to Vagin's claim of a 20-kV operating voltage at 500 microns.

The anode commutation delay, measured from the start of cathode cavity conduction, is less than 20 ns. Cathode delay (and hence tad) and jitter, however, measured from the time at which voltage (-2 kV) is applied to the cathode cavity, are both in the microsecond region.

The impregnated cathode tube has not been completely characterized. Preliminary operation on a thyratron test kit indicates that its operating characteristics, as evidenced by holdoff, recovery time, anode delay, and jitter are those of a normal thyratron.

These observations do not pertain to start-up conditions. The low driver voltage available, 175 V, while adequate for maintaining the tube in operation, is too low for initial breakdown; thus preheating of the cathode was required. It is likely that under true cold-start conditions the long cathode delay contribution to tad would, as with the Autron, still be evident.

It is apparent that our results are not in accord with Vagin's description of the Autron's operation. Of the major discrepancies, the insensitivity of the anode pulse to cathode/anode current ratio is an advantage. Similarly, the Autron's ability to commute with a negligible cathode current indicates that tighter grid baffling can be used to improve holdoff without deterioration of the anode delay time.

These conclusions are supported by the preliminary results from the tube of our own design which also indicate that a practical cold-cathode thyratron can be realized. The only serious defect that is presently suspected in this tube — long cathode delay at start-up — should be treatable by means of a keep-alive or ignitor electrode.

b. Test Equipment

(1) Experimental Modulator

The experimental modulator circuit diagram and current pulse waveforms are shown in Figure 1. The current-pulse scope shots were taken by switching the PFN's with a mercury relay, no tube being connected to the circuit.

The cleanest signals were obtained by floating the grid, but failure of the two PFN supplies and the relay ensued, and there was some evidence of unequal voltage division during the transient portion of the pulse. These components were replaced and the grid was tied to ground. No further test-kit failures have occurred. The noise component of the current signals from the anode and cathode loops, however, remained a problem. This was solved by replacing the reservoir supply transformer with one having a much lower interwinding capacitance and by using a scope specifically shielded against RFI.

The modulator is presently being operated at epy = 5 kV and 1 pps. PFN capacitors for extending this capability to OPI conditions have been ordered.

(2) Demountable Tube Facility

This facility consists of a glass envelope thyratron, permitting visual observation of the discharge, and an external hydrogen supply. Hermeticity of the envelope parts is maintained with O-ring flanges. Inward extension of the flanges provide mounting support for the internal parts of the tube. The tube assembly is continuously pumped. The desired internal pressure is achieved by bleeding in tank hydrogen via a thermocouple gauge controlled solenoid valve in series with an adjustable orifice.

Construction of this facility should be completed during the next monthly reporting period.

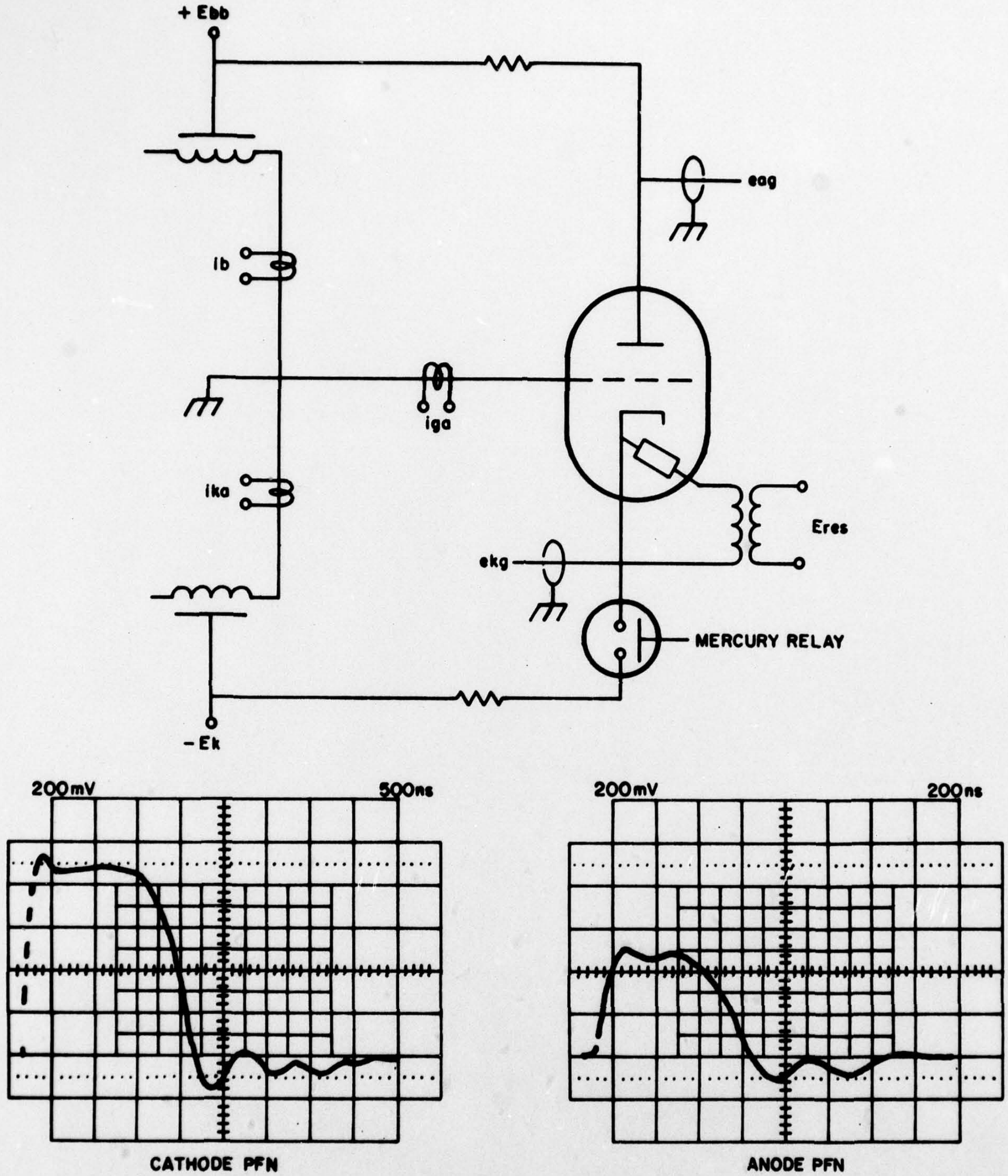


Figure 1. Experimental modulator.

c. Autron Characterization

(1) Tube Configuration

The HY-3203-007, our copy of Vagin's Autron, is shown in Figure 2. The spacings and grid dimensions were taken from Vagin's paper; the only known operational construction difference being our use of molybdenum, rather than copper, for the cathode and grid.

The features that distinguish the Autron from a thyratron are its unheated, high work-function cathode and the absence of a grid-baffle. Baffling depends solely on the field strength decay in the cylindrical grid apertures, which have a diameter-to-length ratio of unity. This "self-baffling" grid permits considerably more penetration of the anode field into the cathode cavity than is the case with thyratrons.

(2) Holdoff Voltage

The 0.080 inch anode-grid spacing of the HY-3203-007 should easily be capable of withstanding 30 kV in the thyratron pressure range. The very low values actually found may result from electrode material deposited on the anode cavity wall during arc-mode operation, or most likely from field penetration through the grid apertures. Holdoff voltages at various internal pressures are shown in Table 2.

Table 2. Autron holdoff voltage.

Eres (volt)	$P(D_2)$ (micron)	Holdoff (kV)
4.5	110	19.3 ± 0.7
5.6	205	18.9 ± 1.1
6.0	264	18.8 ± 0.5
6.3	300	16.0 ± 0.2
7.0	430	9.0 ± 0.4

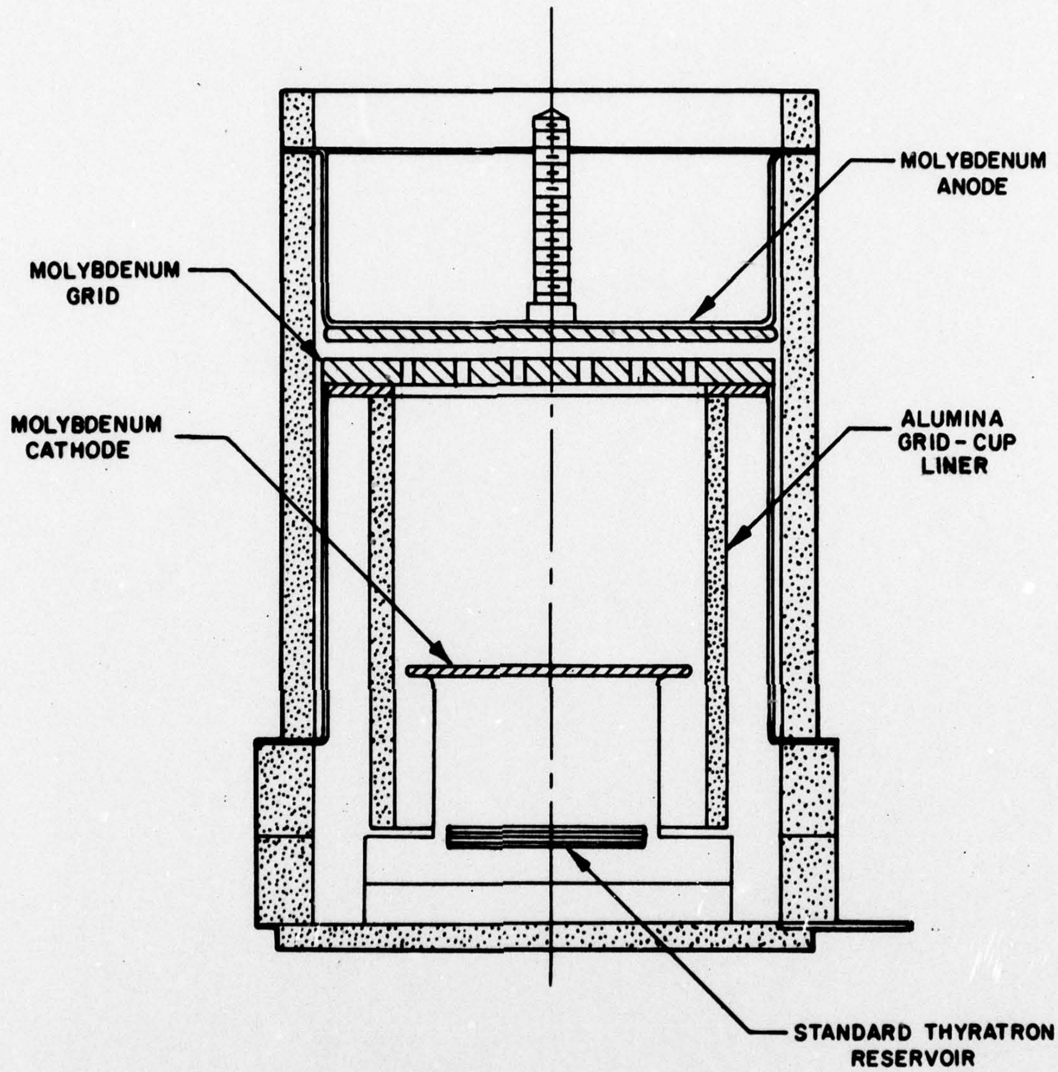


Figure 2. Autron construction (HY-3203-007).

(3) Tube Drop

This measurement was made by putting a TEK 1000X voltage probe across the tube cavity. Typical data are shown in Figure 3. The first of these shows the entirety of the anode voltage collapse. In the next, the vertical sensitivity was increased ten-fold to examine the relatively small portion of sensitivity that pertains to tube-drop. In the case of the cathode cavity, only the expanded trace is shown, the now negative voltage rising from the bottom of the picture. These measurements can be used to infer a total tube drop of about 200 volts, but the need for a more refined measuring technique is apparent; this is discussed under "Future Work."

(4) Time Delay and Jitter

For the purpose of this work the anode delay time, tad, is separated into two components. The first of these, tkd, is the cathode delay, measured from the time that the cathode voltage is applied to the time of cathode cavity breakdown. The remainder of the time required for inception of the anode pulse is defined as the anode commutation time, tac.

Two methods were used to determine tube delay times. In Figure 4, the first scope trace represents the sum of the cathode voltage and the anode current signal. The initial flat portion of the trace is the cathode voltage, time-zero being established by the closing of the cathode PFN switch. Cathode turn-on is indicated by the step displacement of this negative voltage toward zero. The length of this part of the trace is defined as the cathode delay, tkd. This is followed by the positive anode current pulse; the rise of this signal is in apparent coincidence with the collapse of the cathode voltage. Within the resolution of these measurements, the anode commutation delay, as defined above, is tac $\leq$ 100 ns, whereas the total delay, tad = tkd + tac, is microseconds long.

The excessive cathode delays were accompanied by firing time variations of similar magnitude. This prevented using a faster sweep for a more accurate determination of tac. In the second method, only current signals were used, the scope being triggered by the anode pulse. Thus, although the

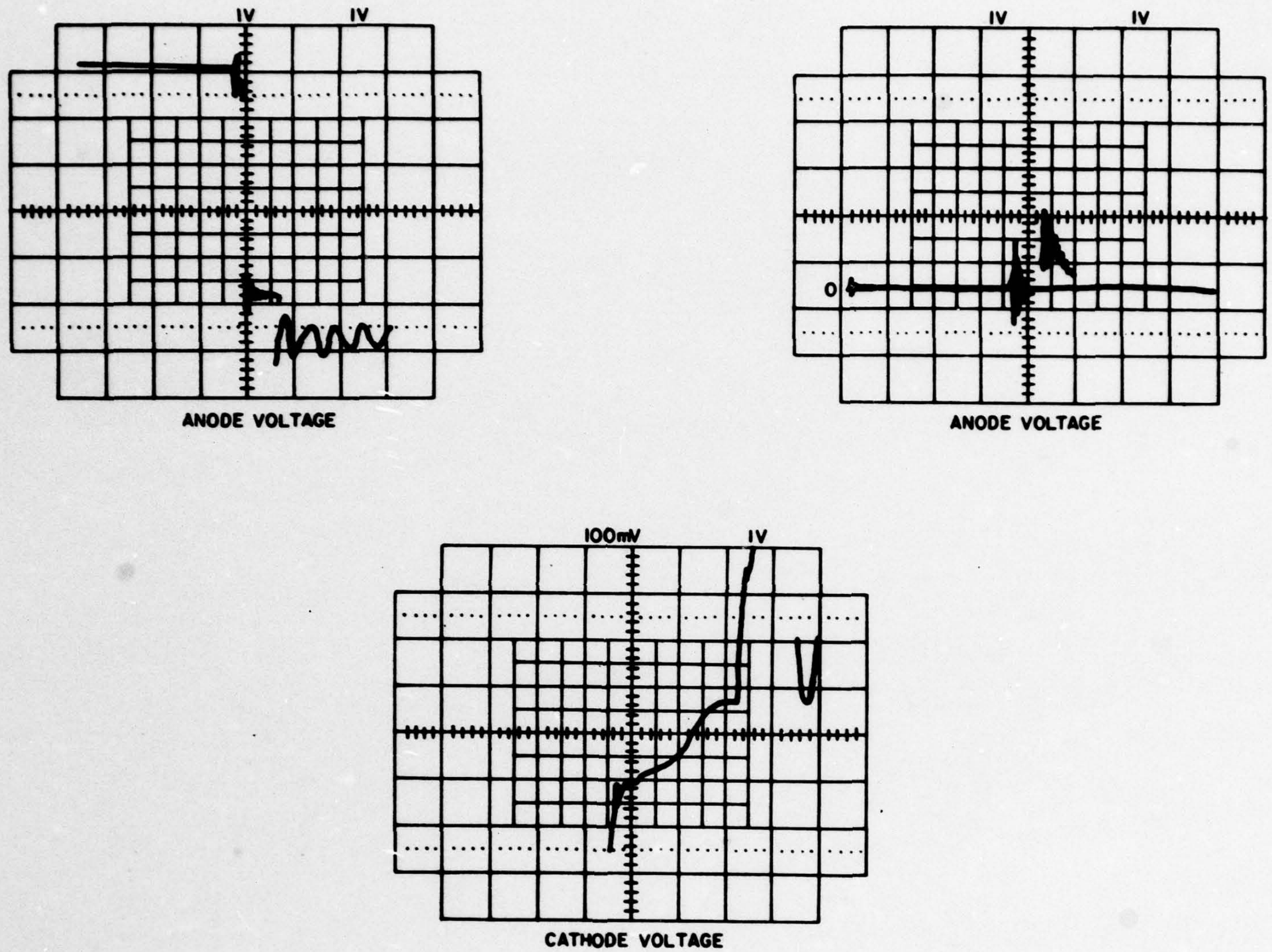
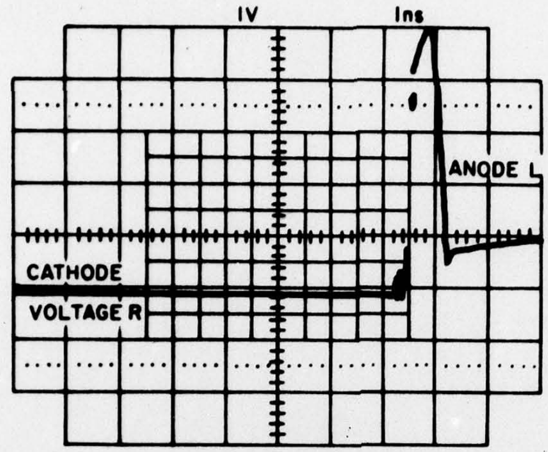


Figure 3. Autron tube drop.



ANODE DELAY

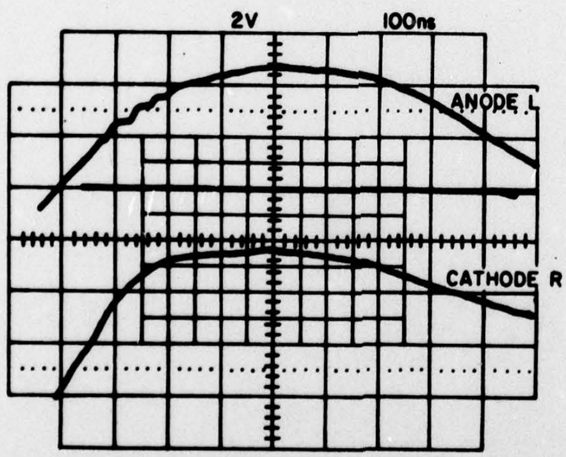


Figure 4. Autron delay time.

anode and cathode traces were taken consecutively, the start of the cathode signal represents the inception of anode commutation. A 100 ns/div horizontal sweep was used, and the intersections of the two current signals with the time axis showed tac $\lesssim$ 10 ns. This same result occurred regardless of the ratio of currents that was in the two loops; tac was also found to be independent of cathode voltage.

Whereas the anode commutation delay is satisfactory, the cathode data give an average tkd = 4.0 ± 0.5 μs for a -2.5 kV cathode voltage, which amounts to overvolting the cathode cavity by a factor of five. Lowering the voltage to -1.0 kV, now overvolting the cathode cavity by only a factor of two, gave such erratic results, 0 to about 15 μs, that these measurements were discontinued. Such random behavior, caused by the statistical nature of the discharge time-lag and its dependence upon the ratio of the applied to static breakdown voltages, are well known. Thus, if overvolting the cathode cavity with the cathode PFN is to be used to initiate tube commutation, considerably higher voltages would be needed. A separate trigger source and a cathode cavity keep-alive are alternative approaches.

(5) Effect of Current Ratio

Table 3 summarizes the current-pulse measurements. For all of these data, the anode PFN and voltage were kept constant, the variation in the cathode-to-anode current ratio being effected by changing the voltage and number of sections of the cathode PFN. The anode current reported is its maximum value, ib, whereas the cathode and grid currents pertain to their values at the time corresponding to this maximum anode value. The good agreement between the measured grid pulse, iga, and its value calculated from the difference between the cathode and anode pulses, ika-ib, demonstrates the integrity of the circuitry insofar as current measurements are concerned. For all values of ika/ib, ranging from 0 to 1.2, the measured anode pulses remained constant within ±4 percent.

Table 3. Summary of current distribution data.

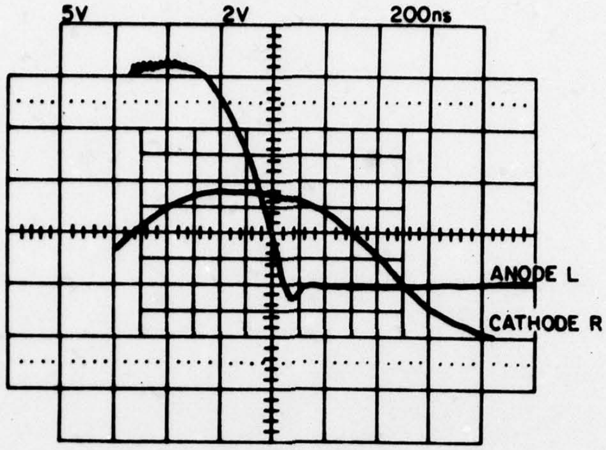
Anode Voltage: Ebb = 5 kV

Anode Pulse Length: tp = 400 ns

Run	Ek (kV)	tp (μs)	ib (A)	ika (A)	iga (A)	ika - ib (A)
44-2	-1	1.2	390	280	-100	-110
44-3	-1	0.6	400	240	-140	-160
45-1	-2	0.6	420	500	80	80
45-2	-1	0.4	420	320	-100	-100
45-3	-1	0.2	405	150	-240	-255

A more detailed examination of some of these data will now be made.

Figures 5 and 6 compare the behavior of the Autron in the ika < ib and ika > ib modes. The corresponding cathode/anode current ratios, 0.6 and 1.2 should, according to Vagin, be representative of the arc and "plasma cathode" modes, respectively; yet, no marked difference in signals is apparent. In Figure 5, the portion of the anode current going to the grid represents a theoretical current density of 4.4 A/cm^2 as compared to the 10 A/cm^2 glow-arc threshold found in Hughes' crossed-field tube. Thus, it is possible that no anode cavity arcing was present. An equally plausible reason for the similar appearance of these two data sets is that anode cavity arcing was present in both. Although, when ika > ib the tube's formal cathode is the ultimate destination for all of the anode pulse, it is possible that this pulse arcs to and then from the grid, as opposed to going through the grid apertures.



ika/ib = 1.2

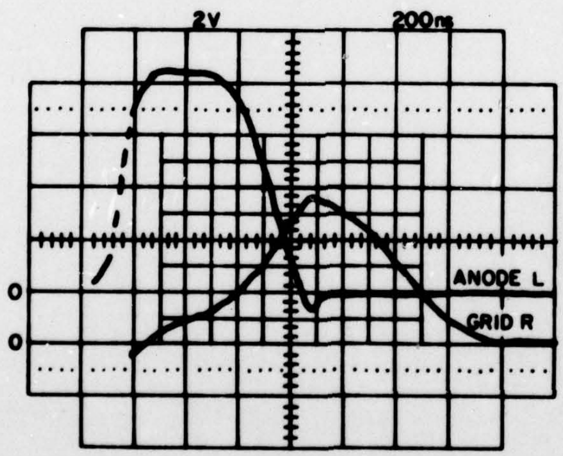
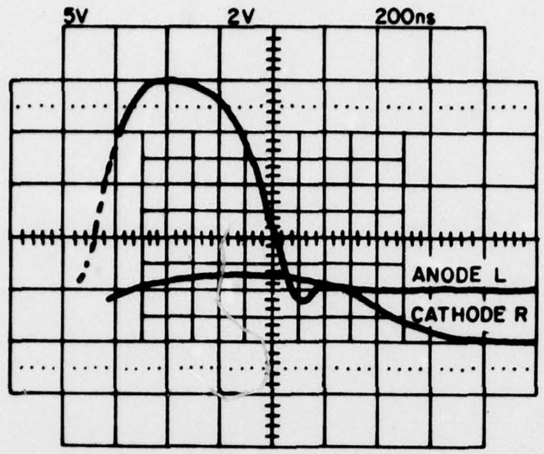


Figure 5. Autron operation: cathode current larger than anode current.



ika/ib = 0.60

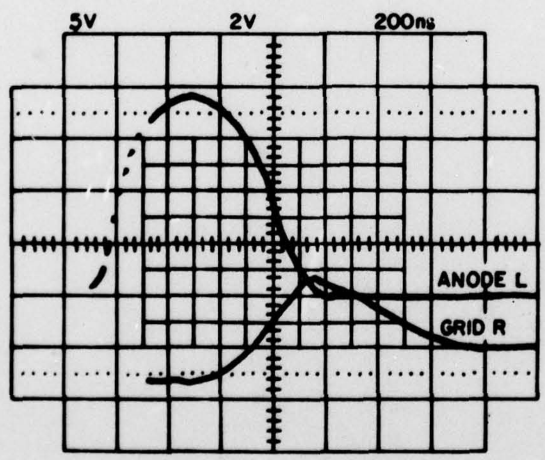


Figure 6. Autron operation: cathode current less than anode current.

In Figure 7, the cathode PFN has been reduced to a single section and is operated at 1 kV to further decrease the cathode/anode current ratio to 0.37. Even this value, however, was not reached until 500 ns had elapsed. The cathode current is essentially zero during the first 200 ns of the anode pulse. During this time, the entire anode signal is conducted by the grid, giving a minimum current density of 13 A/cm^2.

The anode pulse exhibits somewhat more noise than for previous runs, but its appearance is not so markedly different that it could, with any certainty, be ascribed to a mode change. Further, the noise after 400 ns is a damped 45-MHz oscillation.

d. Impregnated Cathode Triode Studies

(1) Tube Configuration

The HY-3203-008 differs from the Autron in that it has an impregnated rather than a "bare-metal" cathode. It also utilizes a separate baffle. This results in intercavity coupling typical of thyratrons, as opposed to Vagin's very open self-baffled grid.

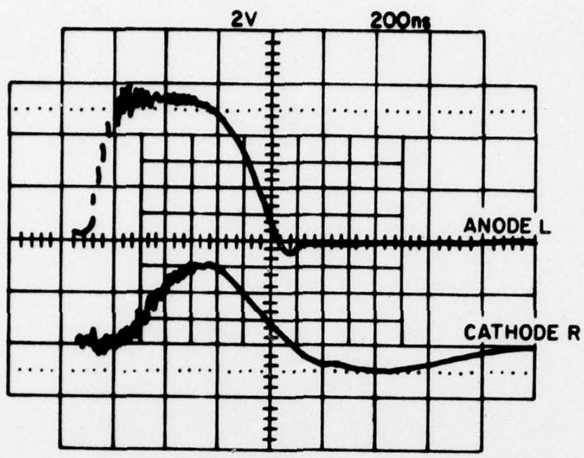
(2) Preliminary Test Results

After cathode activation and processing, the tube was run in the cold-cathode mode on a thyratron test kit for 15 minutes. Data are summarized in Table 4 for grounded cathode operation. The thyratron kit only has 175 V grid drive; this necessitated first starting the tube with a hot cathode, the filament voltage then being turned off. Thus, the data are not literally representative of cold-start conditions.

Time jitter was not measured, but was less than 20 ns. This tube will next be characterized on the experimental modulator.

Table 4. HY-3203-008 operating data.

Eres (V)	Ires (A)	epy (kV)	prr (sec^{-1})	tp (μs)	ib (A)	tad (μs)
8.2	3.8	21	1000	1.0	200	0.25



ika/ib = 0.37
Current ratio = 0, t<200 ns

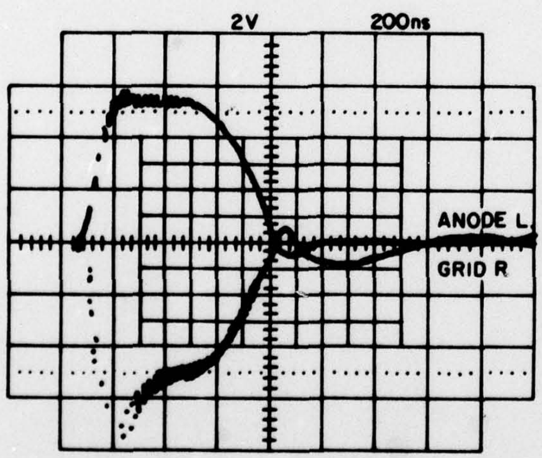


Figure 7. Autron operation: "Zero" cathode current.

3.0 CONCLUSIONS

Our work with the HY-3203-007 Autron tube does not support Vagin's description of its operation. In particular, the insensitivity of the anode pulse shape and commutation time to cathode/anode current ratio suggests that a driver circuit can be used which is more nearly like that of a normal thyratron. These results also imply that a conventional grid and baffle geometry will improve the Autron's unsatisfactory holdoff without undue deterioration of its delay time.

These tentative conclusions are borne out by the preliminary results obtained using the -008 tube. This triode has much tighter baffling than the Autron and shows the desired holdoff improvement while retaining satisfactory delay times.

Two major requirements — reduction of the cathode delay found under cold-start conditions, and satisfactory tube life — remain to be demonstrated. As noted in subsection 2d., the low driver voltage available necessitated starting the -008 tube with the cathode hot. Thus, although the filament was then turned off, the low tad found with cold-cathode operation does not pertain to the initial conditions that one would have with a true cold start. It is expected that the absence of a preformed cathode arc spot will result in the -008 tube having the same excessive tkd previously found with the -007 Autron tube under cold-start conditions. This problem will be corrected by means of a keep-alive or an ignitor electrode. Operation of grounded-grid thyratrons has shown that acceptable longevity can be had in a tube whose conduction mechanism involves arc-discharge phenomena. Our usage of low work-function electrodes will further improve tube life.

4.0 FUTURE WORK

a. Voltage Drop Measurement

More accurate voltage drop measurements are needed to detect possible mode changes in the gas discharge. A shunt diode clipping circuit, to limit the probe voltage to about 200 V, is being investigated. It is hoped that this will eliminate the shock excitation caused by the step-change from epy to the tube sustaining voltage.

b. HY-3203-008 Triode Studies

The impregnated cathode, conventionally baffled -008 triode will be characterized under cold-start conditions. Anode delay times in terms of tkd and tac will be measured. Tube voltage drops will be determined.

This tube permits comparative measurements between hot and cold cathode operation to be made within a single geometry. The results will be valuable in determining the basic commutation differences between the normal and cold cathode modes of operation.

c. HY-3203-004 Tetrode Studies

Preliminary study of the effects of operating with a trigger and/or keep-alive will be made using tubes HY-3203-003 and -004.

d. Demountable Tube Facility

Construction of this facility is on schedule, and will be completed during the next reporting period. The principal application of this setup is to visually determine the location of the arc spot, if grid arcing does indeed occur. Any indicated changes in grid design will then be made. Evaluation of these redesigns will be facilitated by the demountable feature of this facility.

e. Triggered Tetrode Design

The results of 4b. through 4d. will be utilized to design an impregnated cathode, triggered tetrode. Determination of the effects of using a narrow trigger pulse and a keep-alive, both separately and in unison, will be emphasized in the experimental measurements.

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